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COMPARATIVE EVALUATION OF THREE SYMMETRICAL SINGLE SLOPE SOLAR STILLS WITH A SHADING COVER COUPLED WITH EVACUATED GLASS TUBES

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ABSTRACT

In this study, a single slope solar still with a shading cover connected to a solar heating system of evacuated tube heat pipes has been investigated experimentally. Three identical models of this solar distilled have been designed and constructed from the same materials for comparing and studying the effect of the climatic conditions (solar radiation intensity, ambient temperature and wind velocity) and the depth of slain water at the bottom of the solar still on its performance and productivity. The results revealed that the productivity and the average thermal efficiency of the solar still decrease with water depth, and they increase by 24 % and 11 % respectively when the average solar radiation intensity increases from 410Wm^{-2} to 501 Wm^{-2}.

KEYWORDS: Desalination, Productivity, Solar Still, Saline Water, Thermal Performance

INTRODUCTION

The distilled water is the main source of domestic demand in K.S.A. Considered one of the highest in the world, the annual national water demand in Saudi Arabia has increased from 2,350 million cubic meters in 1980 to more than 27,200 million cubic meters and the country is expected to face extreme water shortages [1]. The standard desalination techniques like multistage flash (MSF), multi-effect (ME), vapor compression (VC) and reverse osmosis (RO) are only reliable for large capacity ranges of 100–50,000 m^3/day of fresh water production [2,3]. These technologies are expensive for small amounts of fresh water, and they have limited application in locations such as remote areas. Additionally, the use of conventional energy sources to drive these technologies has a negative impact on the environment [4]. Application of solar energy for sea water desalination in the climatic zones of Saudi Arabia is interesting when saline water is available from underground or from the sea. The use of solar energy with water distillers has a long history and the technology is well improved and field tested, all over the world. The basic design of a solar still is similar to a greenhouse, where the solar energy enters the device through a sloping clear glass or plastic panel and heats a basin of salt water [5]. Solar stills have been thoroughly studied and tested for the production of desalinated water using solar energy. Review of the previous studies of the solar stills can be found in [6]. The performance of the weir concave type solar still has been studied experimentally by Kabeel [7]. His results have shown that the average distillate productivity during the day time is about 4 L/m^2 with a system efficiency of 38 % at solar noon. Samee et al. [8] presented the design and performance of a simple single basin solar still, where the efficiency of the still was calculated as 30.65% with a maximum hourly output of 0.339 L/h at 1300 h. Solar stills suffer from their low productivity due to loss of heat of condensation to surroundings via the glass cover. This problem has been solved by utilizing this heat to heat brine in multi-effect stills [9]. However, no work has been done to make use of the heat dissipated from the bottom of the still, except by insulating the bottom, which does not prevent heat seepage [10]. Badran et al. [11] changed the configuration of the solar still a little bit compared to the one used by Badran and Tahaineh [12] in which double slope solar still was used. They concluded that the mass of distilled water production increased by 231 % in the case of tap water as a feed and by 52 % in the case of salt water as a feed. In this work, three identical single slope solar stills have been tested in the same time to compare the effects of different parameters such as the solar intensity, ambient temperature, wind velocity and the depth of saline water on their efficiencies.

EXPERIMENTAL WORK

This study was aimed at comparing three symmetrical single slope solar stills which, have been constructed and tested under the same climatic conditions. Each of them consists of two principal parts, a single basin which made of a black-painted absorbing plate of 4 mm thick Aluminum sheet with dimensions of (125x80) cm, where the basin is insulated with rock wool of 2 cm thick, and a cover of solid transparent plastic (Perspex) of 4 mm thickness. I thas an inclination of 25° on the horizontal for receiving the maximum solar radiation. This cover is installed on the framework of the basin as shown in Figures 1, 2 and 3. All edges and corners of the solar still were well filled with silicon to prevent any leakage of heat or vapor.

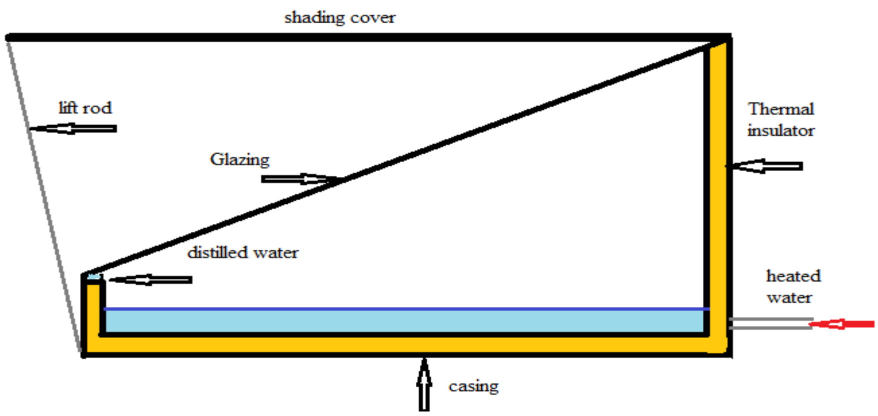

Figure 1: Schematic Diagram of the Single Slope Solar Still

A flat plate of plywood was installed above the solar still as a shading cover to prevent the direct solar radiation access to the basin which works in this case as a condenser in this system. The condenser was connected to the solar heating system where the feed brackish water is heated. Solar stills were mounted at a height about 1 m above ground level on three metallic bases.

Figure 2: Photograph of the Single Slope Solar Still

Figure 3: Photograph of the Solar Heating System

Five calibrated thermocouples of type (K) for each still are used to measure the temperatures in different locations inside the solar kiln and connected to a multi-channels temperature recorder. The solar radiation intensity has been measured by using a CMP 6 KippZonenPyranometer with a Data-logger, and a digital thermometer is used to measure the ambient temperature.

The experiments were conducted throughout the day (over twenty-four hours) to understand the performance of the solar still. Solar radiation, ambient temperature, basin water, cover glass temperatures and still productivity have been measured for an interval of one hour during the duration of data collection.

RESULTS AND DISCUSSION

Case I

In the first run of experiments the three identical solar stills have been filled with brackish water for three different depths of o.8cm, 1.6 cm and 2.4 cm. Figure (4) shows the hourly variation of ambient temperature and solar radiation intensity on typical day of May, 21, 2013. The value of solar radiation intensity started increasing from 06:00 a.m. till it reached its peak period between the hours of 13:00 and 15:00; and the ambient temperature varied in sympathy with the solar radiation and reached their maximum values through the period between 12:00 p.m. and 17:00 p.m., whereas the variation of wind velocity is represented on figure (5). It is clear from this figure that the wind velocity was weak in the first hours of that day and then began to increase after 05:00a.m. with increasing the ambient temperature, the solar radiation and the temperature of the feed water.

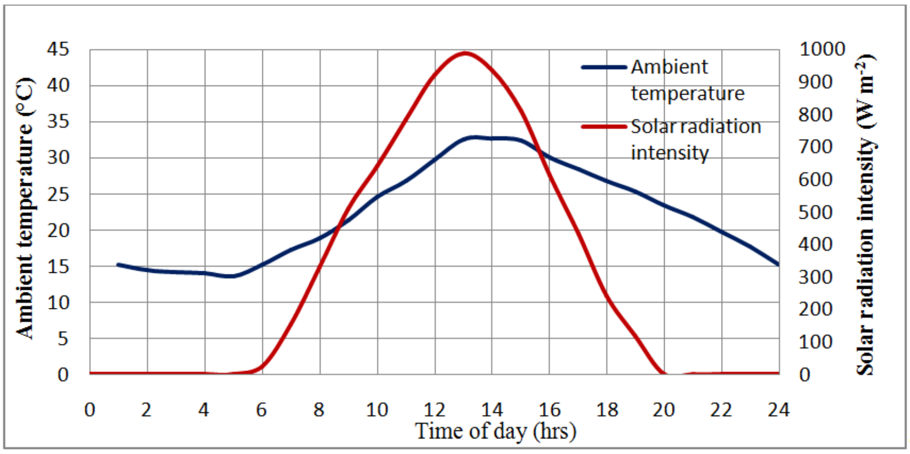

Figure 4: Hourly Variation of Ambient Temperature and Solar Radiation on July, 21, 2013

The final aims of this study are determination of the productivity of distilled water and the effect of variation of the water depth in the solar still.

Figure (6) represents the hourly variation of productivity with three different water depths (H_1= 0.8 cm, H_2=1.6 cm, H_3= 2.4 cm). This figure shows that the productivity was very low in the morning, and then rise to reach its peak between 12:30 p.m. and 15:30 p.m., where the ambient temperature, solar radiation intensity and the temperature of the feed water were much higher. The rate of producing distilled water began to decrease till 19:00 p.m., whilst it increased slightly during the night in due to decreasing the temperature of the solar still cover.

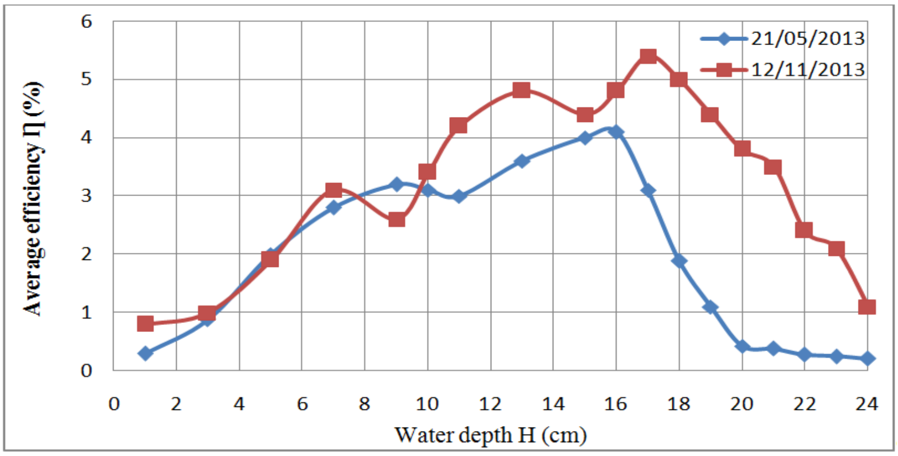

Figure 5: Hourly Variation of wind Velocity on July, 21, 2013 and November, 12, 2013

On the other hand, it is noticed that the productivity of the still with water depth of H_1= 0.8 cm was much better and its maximum value was about 244 cm^3 at 14:00 p.m. comparing with 224 cm^3 and 216 cm^3 for water depths of H_2= 1.6 cm and H_3= 2.4 cm respectively in the same time as shown in figure 6.

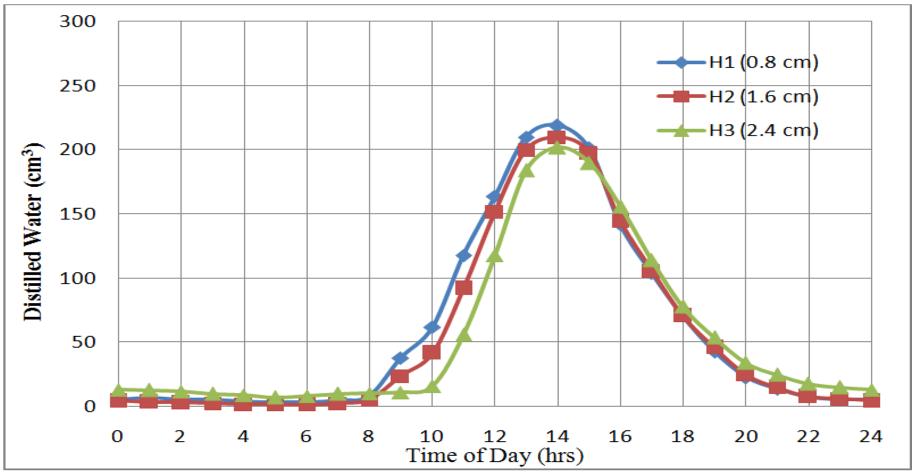

Figure 6: Hourly Variation of Productivity for Three Different Water Depths on July, 21, 2013

This is normal, where the water temperature in the first basin (H_1= 0.8 cm) rises much higher due to small water depth in this case comparing with others two cases (H_2= 1.6 cm and H_3= 2.4 cm), and the evaporation rate will be much better. The productivity of the solar still with H3= 2.4 cm in the period between 07:00 pm and 11:00 pm is bigger than those of H1 and H_2. This outcome is due to heat storage in the saline water in the still which maintain the water temperature for long time at night.

Case II

For the second group of test, A series of experiments has been conducted on the same solar stills with the same water depths (H_1= 0.8 cm, H_2=1.6 cm, and H_3= 2.4 cm). The measurement of ambient temperature, wind velocity and solar radiation intensity, were conducted on November 12, 2013. The corresponding plots for wind velocity, solar radiation intensity, and ambient temperature verses the time of the day are displayed in Figures 5 and 7 respectively.

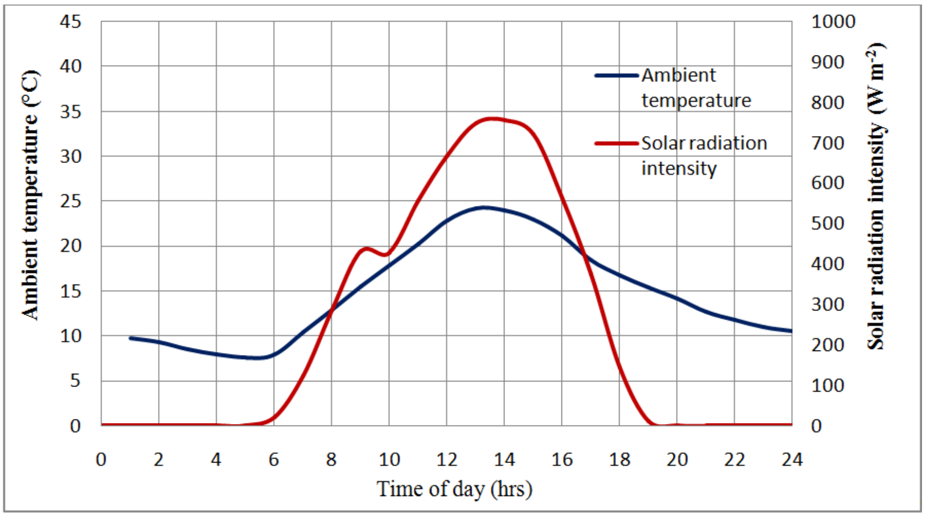

Figure 7: Hourly Variation of Ambient Temperature and Solar Radiation on Nov, 12, 2013

The curves have a maximal value (24.9 °C for ambient temperature and 756 Wm^{-2} for solar radiation intensity) occurring at 13:00 pm and the variation in heating water temperature from 8:00 am to 4:00 pm is limited to 7 °C. Figure 8 shows a comparison between the productivity of solar stills. It can be noted that the productivities increase until reaching their maximum values at 02:00 pm. The productivity of solar stills with H_1 and H_2 in the period between 08:00am and 03:00 pm is bigger than the still with H_3, where as the productivity of solar still with H_3 is better than the two others stills with H_1 and H_2 in the period between 04:00pm and 23:00 pm, it is due also to the effect of heat storage in the salt water, which will be more effective in the case of H_3= 2.4 cm.

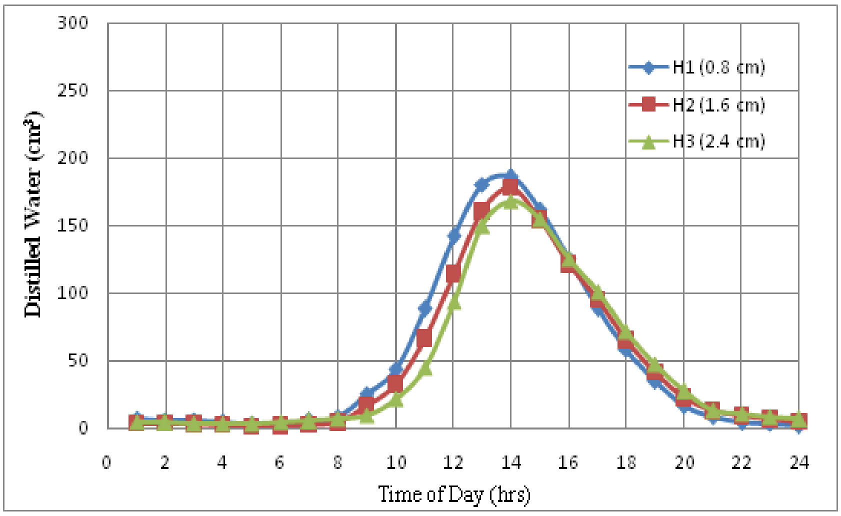

Figure 8: Hourly Variation of Productivity for Three Different Water Depths on Nov, 12, 2013

SOLAR STILL PRODUCTIVITY

The daily solar still productivity is defined as the quantity of fresh water in kg produced by surface unit of the still base. It is done by:

$$P_W = M/A \tag{1}$$

Where:

P_W daily still productivity (kgm^{-2} day^{-1})

$M = \sum V . \rho_w$ daily distilled water (kg day^{-1})

V daily distilled water (m^3 day^{-1})

ρ_w distilled water density (kg m^{-3})

A area of the solar still base (m^2)

The calculated daily productivity of the investigated three solar stills for the two cases (I and II) was done in table (1).

Table 1: Variation of Daily Productivity of Solar Stills with Water Depth

Solar Still		I	II	III
Water Depth (cm)		0.8	1.6	2.4
Daily productivity (kg m^{-2} day^{-1})	Case I (21/5/2013)	4.838	4.523	4.465
	Case II (12/11/2013)	3.99	3.689	3.597

Figure 9 presents the variation of the daily productivity with the water depth in the solar stills. The daily

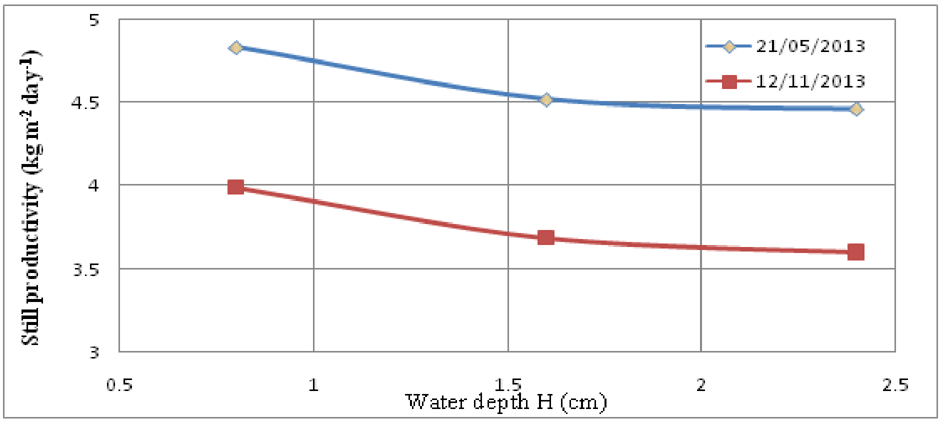

Figure 9: Variation of the Daily Productivity with the Water Depth in the Solar Stills

Productivity of the solar still was decreased with water depth and reached its maximum value of 4.838 kg.m^{-2} at the water depth H_1 = 0.8 cm. Figure 9 shows that the productivity of the solar still increases by 21.25 % for H_1 =0.8 cm and by 24.13 % for H_2 =2.8 cm when the maximal value of the solar radiation intensity increases from 756 Wm^{-2} to 988 Wm^{-2}.

Thermal Efficiency

The average thermal efficiency of the solar still can be calculated by the following equation [13]:

$$\eta = \frac{L \times \bar{M}}{A \times \bar{I}} \tag{2}$$

Where:

$\bar{M} = \frac{\sum V \rho_W}{t}$	average daily distilled water	(kg day^{-1})
t	time of measurement	(sec)
L	latent heat of water at the water surface temperature	(kJ kg^{-1})
$\bar{I}$	average solar radiation intensity	(Wm^{-2})

The average thermal efficiencies for solar stills which calculated by the eq. (2) are done in table (3), and their results are plotted as shown in figure 10.

Table 2: Variation of the Average Thermal Efficiency of Solar Stills with Water Depth for Case i and Case II

Solar Still		I	II	III
Water Depth (cm)		**0.8**	**1.6**	**2.4**
Average efficiency η %	Case I (21/07/2013)	51.91	49.31	48.35
	Case II (12/11/2013)	46.70	44.43	43.53

The values of the average thermal efficiency of this still increases by a stable percentage of 11% approximately by comparing the two cases (I and II), for three water depths H_1, H_2 and H_3.

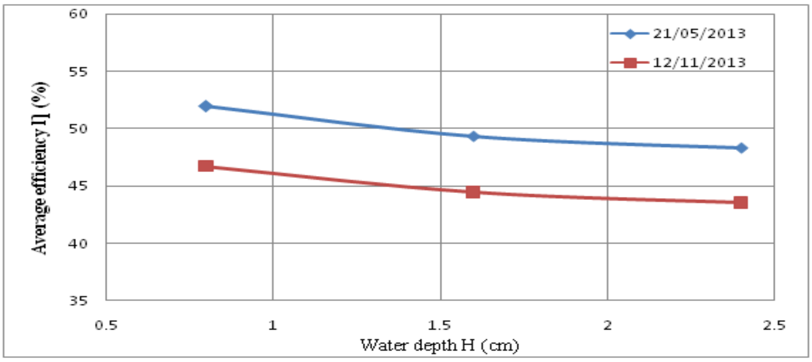

Figure 10: Variation of the Average Thermal Efficiency of the Solar Still with the Water Depth

CONCLUSIONS

An experimental study was completed comparing the performance of three single slope solar stills with different water depths H_1, H_2 and H_3 under the same weather conditions. Comparisons of the yields between the two cases (I and II) which were studied, it was found that the average efficiency and the productivity decreased with the water depth in the two cases, and their maximal values increase by 11% and 24% respectively by comparing them between case I and case II. The tested solar still is useful for rural regions, where the wells and aquifer water is not suitable for drinking due to its salty. The future development of this still for improvement its productivity is using of PCM for heat storage where the evaporation will be continued at night.

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